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THE RHYTHMIC CYCLES IN MAN

Herbert Pollack

Federation of American Societies for
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Human Resources Research Office
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Arlington, Virginia 22209

by

Herbert Pollack, M.D., Ph.D.

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There is ample evidence to accept the concept of a multiplicity of cyclic and rhythmic functions in plants, animals and man. These vary from the ultradian and circadian to seasonal and annual cycles. There are numerous factors involved in these cyclic phenomena, from photostimulation (day-night cycle) to exhaustion-replenishment feedback mechanisms. The multiplicity of rhythms associated with many animals in their development, feeding and sexual habits, as well as in migratory patterns are

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typical examples of biological importance. Darwinian selection of the insect life with these rhythmic habits leads to perpetuation of the species rather than its dissappearance. In the case of migratory birds, rhythmic patterns related to the reproduction and feeding are important in continuity of the species. However, in man, the evidence for this clear-cut necessity of circadian rhythms or the importance of circadian rhythms in his daily life is inconclusive. Man's ability to override the rhythms is an important factor which allows him to undertake many activities and not be limited by the rhythmic nature of these underlying mechanisms. The override capability enables him to maintain his work performance efficiently providing he is motivated and interested. Thus motivation may be more important than the circadian rhythm which can be disrupted but restored easily with the proper stimulation. The report reviews research in this field and notes areas for future research and names key investigators.

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FOREWORD

The Life Sciences Research Office (LSRO), Federation of American Societies for Experimental Biology (FASEB), provides scientific assessments of topics in the biomedical sciences. Reports are based upon comprehensive literature reviews and the scientific opinions of knowledgeable investigators engaged in research in specific areas of biology and medicine. In addition, LSRO utilizes consultants to prepare reports on special topics where their expertise is applicable to particular needs for review and analysis.

This technical report was prepared for the Human Resources Research Office, Defense Advanced Research Projects Agency (DARPA), Department of Defense, under contract number F44620-74-C-0077 monitored by the Air Force Office of Scientific Research.

Under terms of this contract, LSRO agreed to assess recent developments in research on rhythmic cycles in man and their effects on performance. This report was written by Herbert Pollack, M.D., Ph.D., who served as a special consultant to the LSRO for this study.

The report was reviewed and approved by the LSRO Advisory Committee (which consists of representatives of each constituent society of FASEB) under authority delegated by the Executive Committee of the Federation Board. Upon completion of these review procedures, the report has been approved and transmitted to DARPA by the Executive Director, FASEB.

While this is a report of the Federation of American Societies for Experimental Biology, it does not necessarily reflect the opinion of all of the individual members of its constituent societies.

C. Jelleff Carr, Ph.D.
Director
Life Sciences Research Office

SUMMARY AND CONCLUSIONS

There is ample evidence to accept the concept of a multiplicity of cyclic and rhythmic functions in plants, animals and man. These vary from the ultradian and circadian to seasonal and annual cycles. There are numerous factors involved in these cyclic phenomena, from photostimulation (day-night cycle) to exhaustion-replenishment feedback mechanisms. The multiplicity of rhythms associated with many animals in their development, feeding and sexual habits, as well as in migratory patterns are typical examples of biological importance. Darwinian selection of the insect life with these rhythmic habits leads to perpetuation of the species rather than its dissappearance. In the case of migratory birds, rhythmic patterns related to the reproduction and feeding are important in continuity of the species. However, in man, the evidence for this clear-cut necessity of circadian rhythms or the importance of circadian rhythms in his daily life is inconclusive. Man's ability to override the rhythms is an important factor which allows him to undertake many activities and not be limited by the rhythmic nature of these underlying mechanisms. The override capability enables him to maintain his work performance efficiently providing he is motivated and interested. Thus motivation may be more important than the circadian rhythm which can be disrupted but restored easily with the proper stimulation. Possible future research in this field is discussed in the report and summarized in Section IV.

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I. INTRODUCTION - THE NATURE OF THE PROBLEM

Studies of rhythms have emerged from the mysticism which previously surrounded them; yet, one still finds remarks such as "Certain authorities regard rhythms as a fundamental law of nature" (Dubois, 1959). Most authorities would agree that such an attitude stifles further investigation (Mills, 1966). Nevertheless, the recognition of the existence of "biological clocks" has stimulated research for many years even though observations on man are difficult because social, economic, environmental, and related factors play such an important part in his daily habits. Similarly, it is difficult to differentiate conditioned reflexes from rhythmic variations. On the other hand, there are certain physiological processes in man that are somewhat independent of environmental factors; for example, consumption of a meal containing carbohydrates may influence blood sugar, phosphate, potassium and other substances for several hours, and variations in urinary excretion of potassium may be related to blood levels and tissue concentrations.

Social aspects of the problem tend to complicate the interpretation of results. There are many reasons workers are required to deviate from the standard 8-hour work day and the usual rest period as well as from the conventional day-night cycle. In the military these deviations are more important and numerous than in civilian life. Civilian aviators, bus drivers, locomotive engineers and similar personnel go through regular day-night work cycles. Other workers, such as policemen and firemen, interrupt the rhythmic patterns by shifting from night to day periods frequently without apparent undue adverse effects. Physicians as well as others in the medical field are prone to disturbances in the sleep-work cycle which interfere with rhythmic activities. While there is a tendency for people to refer to a sleep deficit, performance on irregular work-rest cycles does not always exhibit deleterious effects of interference with "normal rhythms."

It is natural that the subject of biorhythms should appeal to the more imaginative people. The recent publicity given to the study of airplane pilots and biorhythm cycles as a factor in crashes has created a stir among readers of daily newspapers (Zito, 1975). Entrainment and phase-shifting occur with normal and altered patterns of light-dark cycles. Jet travel across time zones results in phase shifts that are frequently uncomfortable and may be long lasting (McFarland, 1974). Industrial shift workers have a variation in efficiency, error and accident rate which fluctuates with the time of day and their work cycle (Luce, 1970, pp 134-135).

The military interest in this area is derived from the complexities of modern military requirements and the multiplicity of duty hour changes that occur in a variety of functions. This is illustrated in the case of the submarine crews (Kinney, 1963).

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The numerous factors now recognized that influence or control biological rhythms are worthy of careful evaluation if we are to understand these phenomena and use them advantageously.

II. BIOLOGICAL RHYTHMS

A. TYPES OF BIOLOGICAL RHYTHMS

All living things exhibit rhythmic patterns, extending from very short duration oscillatory phenomena such as nerve pacemaker potentials, through daily rhythms, and to those physiological and behavioral cycles that occur monthly, annually or in longer periods.

Circadian rhythms are generally physiological or behavioral phenomena occurring in approximately 24 (24 ± 4) hour cycles. Ultradian rhythms are oscillations with periodicity ranging from 1 minute to 2 hours or more per cycle. Diurnal cycles pertain to the day as distinct from nocturnal; however, in published data on biological rhythms, diurnal is often used as a synonym for circadian.

One of the biological parameters that has been carefully studied during investigations of biological rhythms is body temperature. Changes in body temperature depend on the balance between heat production and loss. As early as 1926, it was noted that heat production varied circadianly and that this rhythmicity probably resulted from variations in muscular rest and activity (Bornstein and Völker, 1926). However, body temperature has a clear circadian rhythmicity that is independent of such factors as experimentally altered sleep-wake cycles and modified photoperiods; and it cannot be explained simply by the effects of rest and lack of physical activity. Circadian periodicity has been recorded in a wide variety of circulatory functions, i.e., pulse rate, blood pressure, cardiac output and stroke volume, venous pressure, linear velocity of flow, pulse wave velocity and circulating blood volume (Menzel, 1962). The increment in pulse rate during a few minutes in the upright position is likewise less at night than during the day. Many of these rhythms are independent of sleep and persist in subjects continuously recumbent and taking small, regular meals.

In subjects infested with microfilariae the organisms are numerous in the peripheral blood during the night but accumulate in the pulmonary capillaries during the day (Hawking, 1973). Another infective species, (*Loa*, sp.) appears in the peripheral blood during the day and retreats to the lungs during the night. The regularity of this behavior is critical to propagation of the invading organisms because it insures microfilariae in the skin vessels at the time when the vector feeds. Forced reversal of the temperature rhythm of the monkey will reverse the rhythm of microfilarial movement to the skin. This technique offers an approach to the control of host-circadian rhythm responsible for microfilarial behavior. Malarial parasites

appear in the blood of the victim where the insect vector is available to feed. This phenomenon includes not only a circadian host rhythm but also a 9-month rhythm related to the availability of mosquitoes during certain times of the year (Hawking, 1973).

B. BASES OF RHYTHMICITY

Most biological functions under circadian influence can be altered in various ways but the circadian component may become apparent only when other factors are minimized. For instance, the circadian rhythms of cardiac frequency and metabolic rate become apparent when exercise ceases or posture change is avoided (Mills, 1966).

Siegel (1969) has distinguished two forms of biological periodicity: exogenous periodicity, which exists as long as the environmental factors change periodically and endogenous periodicity that functions as a biological clock after establishment of a certain time pattern. In exogenous periodicity, the periodic changes of the surroundings play the role of "zeitgeber" (literally, time-giver) or synchronizers to which the organism responds. Zeitgebers can be either environmental factors, such as light, darkness, temperature, tidal and other geophysical forces or regularly repeated physiological processes such as sleeping, eating or elimination. Changes in the hours of daylight and variations in environmental temperatures are the most effective and most obvious zeitgebers. Periodicities, such as the day-night cycles, and temperature changes do not cause an oscillation of the living system but entrain the organism or biological process to a pattern of oscillation. Under normal conditions, the zeitgeber is a regulator which keeps the organisms' frequencies or oscillations in step with the external stimuli.

Unicellular organisms also have a variety of rhythms that persist within a circadian period. The fact that their periods are circadian but not exactly 24 hours, is critical in that it indicates the timing may rely on an internal mechanism rather than on an external physical periodicity (Hastings, 1972).

The major circulatory variables are interrelated and some are clearly related to circadian rhythms. The immediate adaptation of pulse rate to a day of 18 or 28 hours suggests that endogenous rhythm cannot be controlled and the pulse rate (low during rest and sleep and higher during activity) is determined largely by habit. Only when these influences are small is pulse rate also determined by the rhythm of body temperatures. Apparently the environmental factors of living in the normal diurnal-nocturnal existence are more important as zeitgebers than are the habits of the subject.

Rhythm in blood corticosteroids completely disappeared in a man who spent 3 months alone underground even though he followed a regular circadian cycle of activity, eating and sleeping (Mills, 1964). With subjects in a day-night pattern, when urine collections were separately analyzed in two 12-hour portions, the rate of aldosterone excretion was higher by day than by night (Muller *et al.*, 1958). This difference disappeared in subjects recumbent or even sitting during the day and was therefore interpreted as a simple example of the known effect of posture on aldosterone production.

Oscillations in discrete biochemical systems are recognized. Boiteux, according to Blank (1975) described oscillations of glycolysis and cellular respiration during morphogenesis in unicellular algae. It was suggested that there was some type of feed-back related to adenosine triphosphate (ATP) and adenosine monophosphate (AMP) in these systems that was associated with these oscillations. Biochemists are usually interested in the control mechanisms governing normal steady state levels under different conditions and in the kinetics of change between them. However, the oscillations in these fundamental metabolic systems offer another way of approaching the biochemical basis of circadian rhythms in living organisms.

III. RHYTHMIC CYCLES IN MAN

A. SIGNIFICANT HUMAN RHYTHMS

Daily rhythms of sleep and wakefulness, body temperature, hunger, eating, excretion and other functions are a recognized facet of life. Aschoff, (1965) who tabulated more than 100 functions in man that exhibit circadian features, also showed that humans live a true circadian day. Most have periods longer than 24 hours so that, after 20 days in a free-running experiment, a subject who has developed a 26-hour period would have lost almost two solar days; however, subjects are not aware of this change. According to Aschoff (1965), man possesses an endogenous circadian, or ubiquitous circadian clock mechanism. Many recent studies have been prompted by the search for proof for this concept.

A recent publication of the U.S. Department of Health, Education, and Welfare (Luce, 1970) has set forth in excellent detail many aspects of human biology in health and disease which involve clock-like rhythms. Among the many interesting findings are those which show that animals and man may be far more susceptible to drugs at one time of day than at another. Sensitivity to x-rays also may vary with time of day. With high speed jet airplane travel it is possible to go from one time zone to another and return very rapidly. The problem of orientation to time zone changes while maintaining an efficient work schedule has not been resolved. Until recently, mass movement of troops was by surface transportation, frequently long sea voyages. During this time, troops had adequate opportunity to reorient their climate accommodation and circadian rhythmic cycles. With the ability to transport troops half way around the world in a matter of 15 to 20 hours by jet airplane, it is essentially impossible to maintain work efficiency under these rather adverse conditions.

There is an increasing interest in the biological rhythms in the frequency range of 1 or 2 minutes to 144 minutes per cycle (Globus *et al.*, 1973). The interest in these ultradian rhythms originates from the striking temporal organization of sleep wherein the nonrapid eye movement and the rapid eye movement sleep are altered. This relationship is usually on the basis of a 101.5 minute cycle. There is evidence that ultradian rhythms occur during waking hours as well as during sleep hours. Globus *et al.* (1973) summarized their views as follows, "Although these data provide further support for the notion of ultradian rhythms in human behavior studies in the laboratory ambience, it is by no means clear if ultradian rhythms are of particular importance in the 'real world'. Before pragmatic use can be made of these findings this issue must be clarified. It is of interest to note at

this time that the usual exercise and work period in the daily life is the 50 minute work and 10 minute break. This does not conform to the 101.5 minute cycle related to ultradian rhythms."

Orr *et al.* (1974) have identified patterns of ultradian rhythms in heart rate and performance measurements of normal subjects required to perform a standardized vigilance visual-motor response task for periods as long as 48 hours. Using the complex demodulation analyses of electrocardiograms and motor responses developed by Orr and Hoffman (1974), they observed changes in individual ultradian patterns that were indicative of cumulative effects from sleep deprivation and continuous vigilance. The complex demodulation technique is essentially computer-assisted analog band-pass filtering which provides both phase and amplitude data throughout any chosen time series. Modulation of a frequency band can be studied in the time domain of interest for the duration of the measurement period.

In ongoing studies, these investigators are monitoring the electrooculogram, electroencephalogram, electrocardiogram and the electrogastrigram of normal subjects and drug addicts during withdrawal. Preliminary data analyses by related complex demodulation techniques suggest that there are a number of normal ultradian phenomena with a periodicity of 50 to 120 minutes. These investigators believe that ultradian rhythms may be labile, and may be compressed in time with stress. If this hypothesis is correct, then ultradian rhythmicity may be an important aspect underlying human performance, vigilance, and sustained activity. Alterations in periodicity of ultradian rhythms, if measurable, might serve as an indication of the impact of stress on individuals in dangerous operations or threatening situations.

When someone fails to consume food for longer than 6 to 8 hours his energy source reverts almost entirely to the use of reserve nutrients to carry on body functions. When the person is asleep or at complete rest and fasting for 6 to 8 hours, the body stores of glycogen are able to maintain the blood glucose levels. On the other hand, if the individual is engaged in moderate to high activity, the blood glucose concentration might be reduced substantially. Because the central nervous system uses glucose almost exclusively for energy, this system could be adversely affected during total nutrient deprivation of sufficient duration to depress the homeostatic control mechanisms. Because food consumption is on a cyclical basis it is possible for efficiency of brain function to decrease if an inadequate energy reserve occurs during a food deprivation-high activity phase.

In some military aircrews nutrient deprivation is relatively frequent. In certain aircraft, particularly fighter-bombers, food consumption is often make-shift despite occasional 10 to 12 hour missions. Civilian aircraft pilots who undergo multiple time-zone changes, frequently omit meals.

Their inability to obtain desired types of food may also contribute to the omission of meals. The implications are that some functions, particularly those involving high levels of central nervous system control, may be adversely affected by these nutrient deprivations.

B. DISTURBANCES OF RHYTHMS

Some early observations of the effects of changes of the light and dark ratio concern the physiological functions of workers on alternating work shifts (Siegel *et al.*, 1969). In a recent study of the circadian rhythm of body temperature of workers on alternating day and night shifts, body temperature usually peaked during the day and dropped at night. The body temperature of these workers followed the normal circadian time course during the first weekday shift. During the five-week night shift, it showed a different pattern at times of work or sleep; however, for the time between 4 p.m. and 10 p.m., which was a period of leisure on both the day and night shifts, temperature fluctuations showed a pattern very similar to that of the day shift.

The three subjects in this study responded quite differently to the change in work shift (Siegel *et al.*, 1969). One individual adjusted almost immediately to the switch in either direction, whereas the second needed several days to make the adjustment. The third man never adapted completely to the night shift routine. This individual variation in ease of adapting to time changes and establishing new pattern habits has been observed many times and the reasons for these individual differences have been sought, but remain obscure.

Desynchronization of rhythmicity may occur under appropriate circumstances. For example, it can be produced by manipulating the photoperiods (Vernikos-Danellis *et al.*, 1974). Other secondary synchronizers, such as temperature and electromagnetic fields may influence rhythmicity in the absence of light cues, either in a continuous light or continuous dark environment. Physiological changes in man in response to prolonged bedrest suggested that desynchronization of some circadian rhythms occurred in spite of the fact that the subjects were maintained in a highly structured environment including a controlled photoperiod (Vernikos-Danellis *et al.*, 1974). Because such desynchronization in a defined light environment had not been described previously in healthy subjects, it was important to first confirm this finding and secondly to determine if the change induced by bedrest was sufficiently powerful to cause rhythm asynchrony in spite of the unchanged photoperiod. Such a study confirmed the previous finding that the primary influence of bedrest on body temperature and heart rate rhythms is to reduce the amplitude and change their relationships. Normally entrained

rhythms were altered after approximately 20 days of bedrest, and they lost their normal relationships to the photoperiod and to each other. In addition, bedrest induced a depression of body temperature and an initial bradycardia (Vernikos-Danellis *et al.*, 1974).

Research on these phenomena requires better statistically reliable methods of measuring performance decrement in actual operating situations. More data on the long-term effects of physiological changes are needed especially in circumstances where these changes are cumulative with repeated exposure. In addition to information pertinent to the general adaptation syndrome, data on the reactions of the muscular-skeletal, renal, hepatic, gastrointestinal, and infection-combating systems to the stresses of long duration missions and repeated exposure to sleep loss are needed. Harris and O'Hanlon (1972) list other areas requiring further study of recovery functions in man. They noted physiological studies that should be considered by those concerned with the operational consequence of sleep loss. Such data will be difficult to obtain, and as Klein and his colleagues (1968) have so aptly stated the unraveling of cumulative fatigue into its component parts is extremely complex.

Total bedrest has also been used as an experimental technique in studying rhythmicity. A National Aeronautics and Space Administration monograph reviewed the circadian, endocrine and metabolic effects of prolonged bedrest (Vernikos-Danellis *et al.*, 1974). The significant findings were that bedrest resulted in rhythm asyncrony (blood pressure, temperature, heart rate, thyroid hormones, insulin and other hormones) in spite of well regulated light/dark environment. The most drastic rephasing of heart rate rhythms occurred suddenly on day 23 or 24 in the 14 bedrest subjects but not in the ambulatory controls. Mean daily body temperatures decreased about 1°C in all subjects after 56 days of bedrest. Glucose homeostasis was maintained for the first 30 days of bedrest and was accompanied by a 2.5-fold increase in circulating insulin levels. The insulin and blood glucose levels fell by day 54.

In addition, the investigators noted that growth hormone increased initially with bedrest but decreased after 20 days to well below control levels. The pituitary did not respond to hypoglycemia by a rise in growth hormone secretion. Plasma cortisone concentrations doubled during the first 20 days of bedrest but decreased subsequently to levels below the control values by day 55. Plasma adrenocorticotropic hormone (ACTH) remained relatively unchanged during the first 30 days, but then showed a three-fold increase by day 54. Plasma cortisone was the only hormone whose circadian rhythm did not desynchronize with the photoperiod during bedrest (Vernikos-Danellis *et al.*, 1974).

A rigorous regime of isotonic/isometric exercise did not prevent the endocrine and metabolic effects of prolonged bedrest (Vernikos-Danellis *et al.*, 1974). Changes in circadian, endocrine and metabolic functions

in bedrest are apparently due to changes in hydrostatic pressure and lack of postural cues rather than inactivity in confinement or the blood-sampling schedule. Changes in circulating metabolic and endocrine parameters are unreliable if measured only once per day because their circadian amplitude and peak time are altered during bedrest. Therefore, data should be expressed in terms of 24 hour units. Prolonged bedrest results in apparent insensitivity of glucose response to insulin, or cortisone secretion to ACTH, growth hormone secretion to hypoglycemia, and prolonged bedrest, particularly beyond 24 hours, causes a rhythm desynchronization in spite of well regulated light-dark cycles, temperature, humidity, activity, and meal times and meal compositions. Bedrest beyond 42 days results in periodic hypoglycemia, possibly reflecting meal patterns. Periods up to 20 days are insufficient to fully recover from 56 days of bedrest.

C. EFFECTS OF BIOLOGICAL RHYTHMS ON PERFORMANCE

Theoretical and practical interest continues on the influence of biological rhythms and disturbances of the rhythms on human performance (Colquhoun, 1971). It is recognized that well-motivated persons have a remarkable ability to "override" some of the rhythmic effects. In undersea voyages extending for many months in nuclear submarines, the question of watch or duty time is critical. Where men are entirely dependent on the dark-light cycle from artificial light and do not see the sun rise or set for a long time, there is a tendency for a certain amount of temporal disorientation, a phenomenon which is unexplained. The question of optimum crew schedules has been studied for several decades. Most duty schedules are arbitrarily developed and frequently are made four hours on, four hours off; four on, two off; or eight on, eight off. However, studies of different cycles and different tasks continue to be reported, suggesting that there may be more efficient schedules for many unusual or specific environmental conditions.

It is necessary to differentiate among fatigue, vigilance, alertness, and other components of work requirements of military personnel. For instance, the sonar operator must sit many, many hours, and listen for sonar echoes and may receive a negative response. However, he must remain alert to detect the single, sudden change that may be important to the life of the crew. Similar problems face the radar observer when a blip appears on his screen. The man must be alert enough to recognize the pip on the first sweep of the arm rather than to wake up suddenly after the pip has been there for a multiple of sweeps. Fatigue diminishes alertness and rest-work cycles will alter the vigilance of the crewman.

In man, numerous experiments have demonstrated that the daily fluctuations of physiological and psychological functions show maxima and

minima at certain times of the 24-hour day. Fluctuations are of practical importance since there is evidence that these rhythms are associated with temporal fluctuations in efficiency and performance. For example, there are diurnal variations in performance efficiency in many tasks, such as sentry duty, automobile driving, radar observation, and other mental and psychomotor tasks.

There have been numerous studies of the effects of work-rest cycles on performance of tasks that require vigilance, alertness, or sustained motor or mental activity. These investigations studied only specific tasks and consequently, results were difficult to compare with one another. For example, Froberg *et al.* (1972), in a study of circadian variation in psychomotor performance, investigated fatigue and total urinary catecholamine excretion during prolonged sleep deprivation and found that urinary epinephrine was positively correlated with performance and negatively correlated with subjective fatigue while the reverse relations existed for norepinephrine excretion. Frankenhaeuser *et al.* (1968) found a positive relationship between epinephrine release rate and performance efficiency in situations characterized by monotony and understimulation. They noted also that objective performance and subjective reactions in persons differed greatly on the basis of epinephrine output. Specifically, high catecholamine output was associated with performance efficiency.

Similarly, circadian variations were correlated with performance, psychological ratings, catecholamine excretion and diuresis during prolonged sleep deprivation (Froberg *et al.*, 1972). Hale *et al.* (1973) evaluated psychomotor performance during 36 or 48 hour simulated flights, and observed that subjects who alternately worked and rested at 2-hour intervals, showed normal circadian shifting in urinary 17-hydroxycorticosteriods (17-OHCS) for 24 hours. Subsequently, there was an occasional elevation in 17-OHCS output. This study showed also that environmental factors intensified the adrenal-cortical response to imposed work but did not adversely affect psychomotor performance. The increased adrenal-cortical activity is therefore compensatory and contributes to the maintenance of psychomotor proficiency. Nocturnal measurements provided evidence of a progressive decline in epinephrine output with a concomitant gain in 17-OHCS output. Evidently as body reserves at one physiological level declined, an inroad was made gradually on a secondary reserve.

Sleep deprivation has been used as an experimental approach to the investigation of periodic and circadian rhythmic effects on performance (Johnson and Naitoh, 1974). It is difficult to state categorically what the effects of sleep loss of less than 60 to 72 hours would be on performance. Whether a performance decrement would occur during sleep deprivation depends upon complex interactions of task, situational, and personal factors. The nature of the task and its meaning to the subject, particularly its survival

value, are of primary importance in the type of sleep deprivation effects that develop. In the majority of instances, performance decrements occur when the subject becomes sleepy. If the subject can be motivated to remain alert, performance decrement is difficult to detect. After an extensive study of the effects of sleep deprivation the Tufts College group (1949) concluded, "Subjective attitude (mood, appearance and behavior) is the primary factor seriously affected by sleep loss." There have been no studies that have conclusively demonstrated consistent performance decrements as a result of partial sleep loss even though numerous examples of sleep disruption and sleep deficits have been presented.

The paucity of data indicating a clear performance decrement might suggest mistakenly that sleep logistics should be relegated to a minor position in mission planning. Adequate sleep has been emphasized by all researchers as the most important factor in alleviating the problems of repeated time zone crossings and as a means of reducing the physiological demands of air operations particularly in the sophisticated problems of flying a jet aircraft (Preston, 1973). Nevertheless, the decremental performance is difficult to assess accurately in the operational situation.

To obtain a constant reference point to measure changes during prolonged air operations, the normal night minimum of activation point was used as a reference level (Klein *et al.*, 1968). This "standard" or "deadpoint" was selected to control the circadian interference with physiological functions and performance. The circadian cycle is often cited as an important factor in the effects of sleep loss. Sleep loss potentiates the usual performance decrement seen in the early morning hours, and quantity of alpha activity is at its lowest level. Comparison with sleep-deprived groups or between sleep-deprived and nonsleep-deprived groups must be made at the same time of day.

Work-rest schedules such as four hours work, four hours rest do not allow enough time for a reasonable period of uninterrupted sleep. The preferred schedule appears to be nearer 10/10. The cumulative effects of long duration missions may result in a logarithmic rise in load rather than a simple arithmetic increase. In planning flight schedules the most important parameter to maintain an effective sleep-wakefulness pattern may not be the duration of each duty period but the total number of duty hours in relation to the mission duration.

Results of numerous experiments tend to substantiate the hypothesis that the 24-hour variations observed in performance proficiency are indeed a function of the variations in psychological level of motivation or drive level (Miles, 1967). Apparently there is a circadian pattern of drive level and this rhythmic pattern has an effect on performance of all kinds. The effects may be correlated with autonomic responses. However, it is

impossible to tell from the experimental results, whether the apparent differential effects on overt responses and autonomic nervous system responses are real or accidental.

There is a circadian cycle of activation or arousal in the human subject which may affect the learning of new tasks as well as the performance of well-learned tasks (Mosier, 1974). This effect may be similar to the drive-variable effect postulated by Hull (1943). The circadian cycle of activation level is not a smooth monotonic function but contains a definite dip during the afternoon hours and is particularly pronounced on conditioned physiologic autonomic responses.

All available data suggest that the human organism has a great capacity to adapt to exceptional biological requirements. Thus it is difficult to make meaningful generalizations. However, one of the most pertinent facts related to alertness is that under adverse conditions the individual is able to bring all of his capacities to bear on the completion of a task. This is called, variously, "mobilized resources," "overriding," "drive," "motivation," or "ability." Decrements and impairments in performance, alertness or vigilance may be masked by this overriding capability.

There is evidence that responses are learned to internal stimuli as well as external stimuli and that the internal stimuli vary in a circadian pattern. It is interesting to note that when a circadian rhythm has been desynchronized it can be restored very quickly by a very simple return of an old synchronizing stimulus.

IV. FUTURE AREAS OF RESEARCH

Several suggestions for future research are listed below. These concepts have evolved from this overview of the various facets of the rhythmic cycles in man and are not presented in any order of priority:

- Because ultradian rhythms may be labile and their periods may be compressed by stress, efforts should be made to discover whether or not a number of these rhythms can be measured, and their possible practical significance as indicators of performance potential or decrement should be determined.

- Marked individual differences in human adaptability to disturbed circadian rhythms have been observed. An understanding of the reasons for such individual adaptability could lead to important practical applications.

- The need for a practical and statistically reliable method of measuring performance decrement in the operational situation is widely recognized. The development of such methodology could significantly aid the investigation of rhythmic cycle effects on military personnel.

- More data are required on the long-term effects and possible cumulative aspects of the physiological changes resulting from distrubances of biological rhythms in a variety of temporal sequences such as blood sugar levels influencing central nervous system functioning, and body temperature cycles as related to work-rest programs.

- Data on the reactions of the musculoskeletal, renal, hepatic, gastrointestinal, and anti-infection systems to stresses during military missions of long duration with repeated exposure to sleep loss are needed to supplement information pertinent to the general adaptation syndrome.

- The control of body temperature offers a way to clinically influence the biorhythms responsible for microfilarial

infections and this is an obvious approach to the treatment of these infections. Presumably, there may be other significant disease states, disorders, or situations of altered human performance that should be reviewed from the standpoint of possible alteration by control of the rhythmic cycles in man.

The extent to which human performance follows biorhythm curves is a relatively unexplored field. Because research is limited in this area many difficulties are encountered when studies are attempted. The major problem is that biorhythms can indicate only "potential" performance and not the actual level of performance. Biologically an individual's biorhythms indicate only that he is at some peak of his potential; however, innumerable extraneous variables could overshadow these potentials and lead to a decreased performance or an increased performance ability.

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